Non-radiative Nature of Threading Dislocations in GaN Grown by Metal-organic Chemical Vapor Deposition

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Although huge threading dislocations of 10^8-10^{10} cm^{-2} exist in a GaN epitaxial layer grown on a sapphire substrate, the radiative efficiency does not drastically drop [1] and it has been suggested that the dislocations do not act as non-radiative centers. However, it was recently demonstrated that the reduction of dislocations is very effective in improving a lifetime of GaN-based laser diode [2,3]. To solve this contradiction, it is necessary to know not only the radiative emission mechanism of InGaN active layer with threading dislocations [4-7], but also the non-radiative nature of threading dislocations themselves.

We have studied the structure and the optical properties of threading dislocations in a GaN layer and report here the degree of non-radiative nature for each type of dislocation. We categorize threading dislocations in the GaN layer into three types line defects – screw, mixed, and edge dislocations - using the structural characterizations provided by transmission electron microscopy (TEM) and report the optical properties of each type of line defect as characterized by photoluminescence spectroscopy (PL) and time-resolved photoluminescence spectroscopy. We found that screw and mixed dislocations act as strong non-radiative centers. The reduction of these two defects leads to higher performance of GaN-based laser diodes.

Three types of etch pits (refered as α, β, and γ) were observed on the lightly etched surface of Si-doped GaN grown on (0001) sapphire by MOCVD, as shown in Fig.1. The etching was performed by HCl vapor at 600º C. Silicon doping concentration for samples was kept to be [Si]~2×10^{18} cm^{-3}. Using TEM, we found that α, β, and γ type etch pits originated from screw, mixed and edge dislocations, respectively. The shape of the etch pits depended on the strain field around the line defects. The PL intensity of band-edge emission increased as the total density of etch pits corresponding to screw and mixed dislocations decreased from $2\text{x}10^8$ cm^{-2} to $4\text{x}10^6$ cm^{-2}, as shown in Fig. 2. The density of etch pits corresponding to edge dislocations, however, did not change at approximately $3\text{x}10^8$ cm^{-2}. We believe, therefore, that threading dislocations with a screw-component burgers vector, that is, screw and mixed dislocations, act as strong non-radiative centers, and that edge dislocations probably do not. This may indicate that the reduction of threading dislocations, especially those which have a screw-component burgers vector, can improve device characteristics of GaN-based LDs.

Figure 3 shows the photoluminescence decay of band edge emission for sample A and B which have the total density of α and β type etch pits of 4.2×10^6 cm^{-2} and 3.2×10^8 cm^{-2}, respectively. The decay time of sample A and B was estimated to be 250 and 68 psec, respectively. As shown in Fig.2, the PL intensity of the sample B was smaller than that of the sample A. The decay time of the sample B should be, therefore, shortened by the existence of non-radiative recombination centers. Although the difference in the etch pits density of sample A and B was the order of two, the difference in the decay time was only one order. This suggests that the carrier lifetime of non-radiative recombination is comparable to that of radiative recombination for these samples. Suppose that the decay time of sample A is dominated by radiative recombination carrier lifetime, the radiative recombination coefficient (B) is estimated to be 2.1×10^{-9} cm^3/sec.

In the presentation, we will separate the native non-radiative and radiative recombination carrier lifetime of GaN and exactly estimate the radiative recombination coefficient. Moreover, we will discuss a generation mechanism of screw dislocations which act as strong non-radiative recombination centers.

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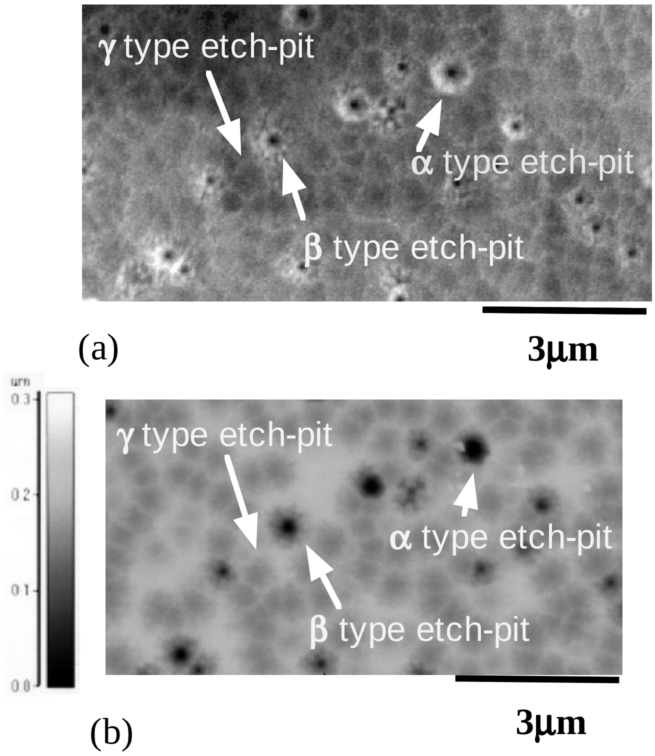

Fig.1
(a) SEM image of the etched GaN:Si surface
(b) AFM image of the same region

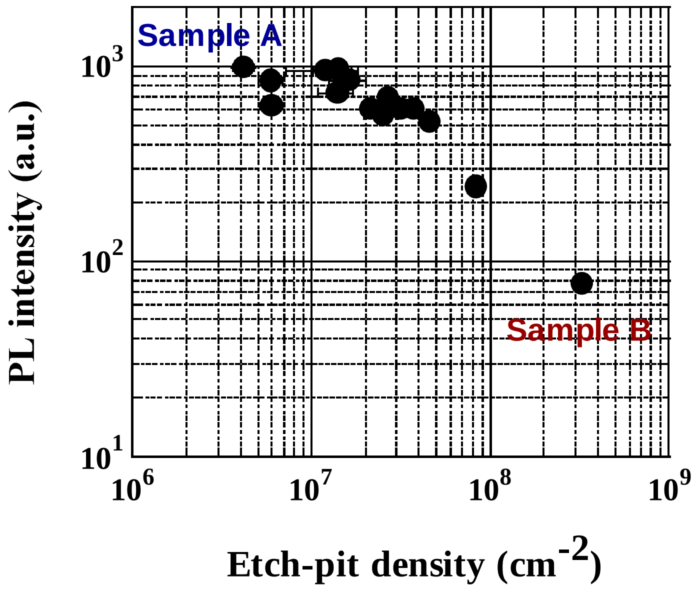

Fig.2
Relationship between the total etch pits density of α and β type and room-temperature PL intensity for GaN:Si. Si doping concentration was kept to be 2×10^{18} cm^{-3}.

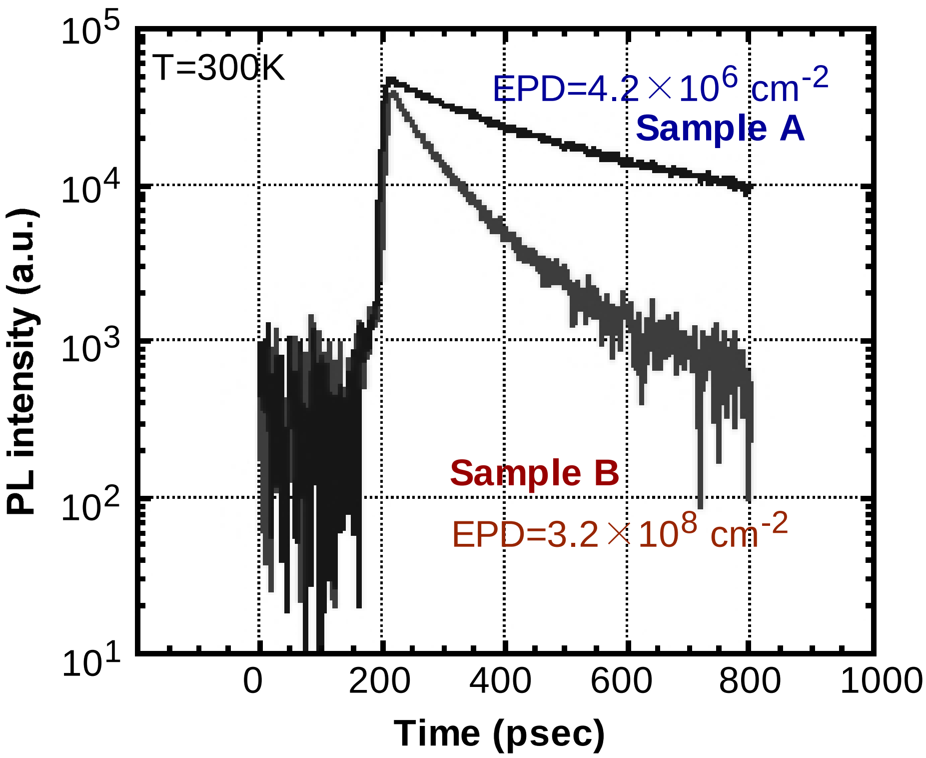

Fig.3 Time-resolved photoluminescence spectrum for Si-doped GaN at room temperature. Sample A and B have the total density of α and β type etch pits of 4.2×10^6 and 3.2×10^8 cm^{-2}, respectively. PL intensity of sample A and B are shown in Fig.2. The excitation energy was 3.594 eV and the detection energy 3.415eV.